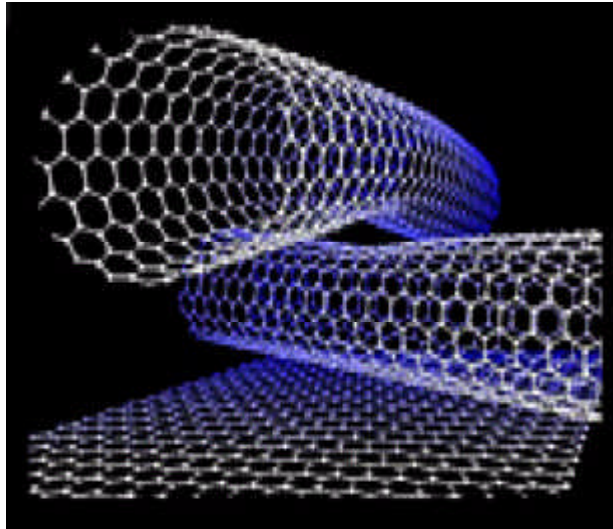


# Carbon Nanotube Anodes Being Evaluated for Lithium Ion Batteries

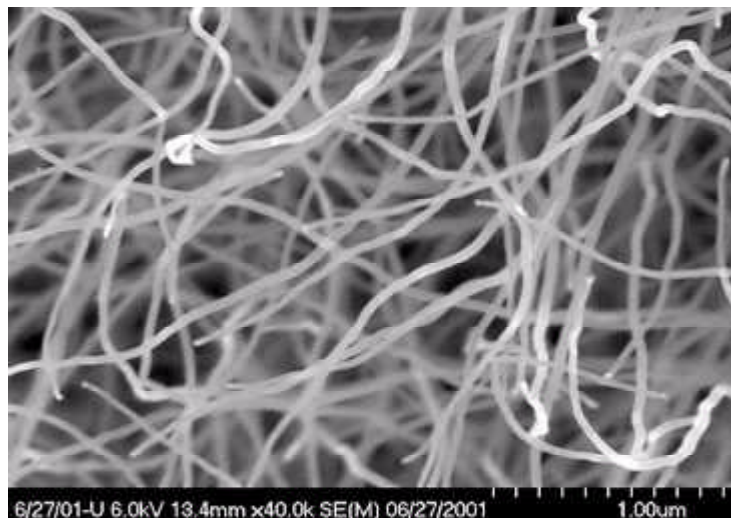
The NASA Glenn Research Center is evaluating the use of carbon nanotubes as anode materials for thin-film lithium-ion (Li) batteries. The motivation for this work lies in the fact that, in contrast to carbon black, directed structured nanotubes and nanofibers offer a superior intercalation media for Li-ion batteries. Carbon lamellas in carbon blacks are circumferentially oriented and block much of the particle interior, rendering much of the matrix useless as intercalation material. Nanofibers, on the other hand, can be grown so as to provide 100-percent accessibility of the entire carbon structure to intercalation. These tubes can be visualized as "rolled-up" sheets of carbon hexagons (see the following figure). One tube is approximately 1/10,000th the diameter of a human hair. In addition, the high accessibility of the structure confers a high mobility to ion-exchange processes, a fundamental for the batteries to respond dynamically because of intercalation.



*Carbon nanotube structure.*

Nanotubes were grown by both laser vaporization and chemical vapor deposition (CVD). The laser vaporization method was used to provide high-purity, single-wall tubes. The CVD approach produced multiwall tubes that could be grown directly on metal foil substrates coated with suitable metal catalysts using a high-temperature furnace.

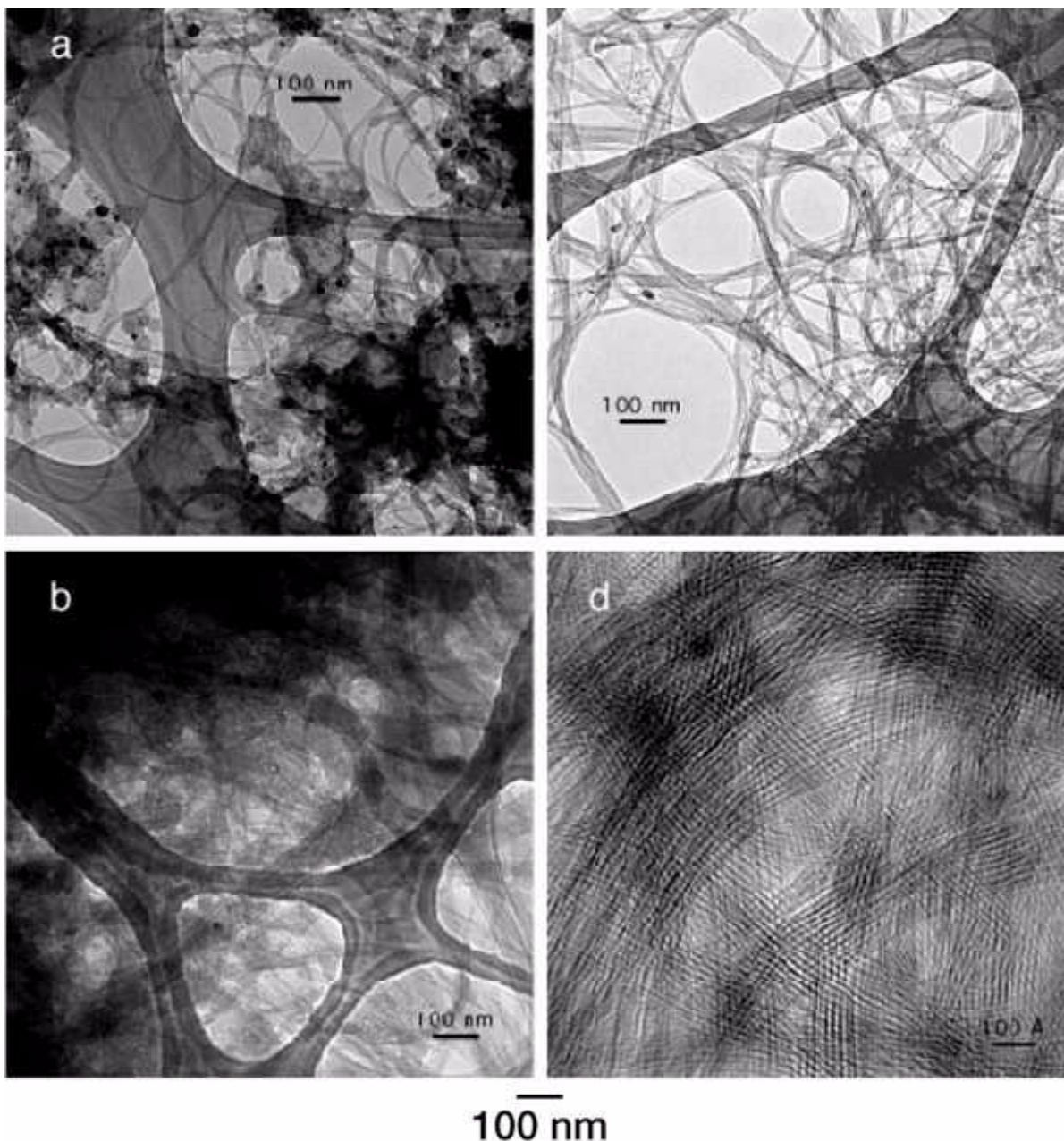
Glenn's researchers have found that evaporated nanoscale copper "islands" on nickel metal-foil substrates provide an excellent substrate for high-purity multiwall nanotube CVD growth (see the next figure). In addition to Li storage for high-energy-density batteries, carbon nanotubes that are deposited by CVD onto metal substrates are of high interest for a wide range of applications such as the filtering of gaseous or liquid media and as reinforcing agents in composite materials.



*High-resolution scanning electron microscope image of CVD multiwall carbon nanotubes.*

The laser vaporization nanotubes were produced in a high-temperature furnace under argon using a 755-nm alexandrite laser and a graphite target doped with Ni and Co. The resulting "soot" was purified by nitric acid refluxing followed by annealing in oxygen. Single-wall carbon nanotubes with a purity greater than 99 wt% have been prepared using this method (see the final figure) (ref. 1).

The anode surface area per mass provided by high-purity nanotube "tape" was found to be greater (by several orders of magnitude) than any conventional anode materials. This increase in area should decrease the internal battery resistance and presumably increase the attainable current densities and the cyclability of batteries utilizing these materials as anodes. The lithium capacity of high-purity carbon nanotube films was measured with a conventional three-electrode cell. Anodes were prepared by casting thin films of high-purity carbon nanotubes dispersed in poly(vinylidene fluoride) (PVDF) directly onto copper foil. The capacity, which showed excellent reversibility, was ~2000 mA-hr/g after 30 cycles. This capacity is over 5 times greater than that of graphite.



*High-resolution transmission electron microscope images. (a) "Raw" laser vaporization soot. (b) Single-wall nanotube bundles after reflux. (c) High-purity (>99 wt%) single-wall carbon nanotubes. (d) Nanotube "tape."*

## References

1. Dillon, A.C., et al.: A Simple and Complete Purification of Single-Walled Carbon Nanotube Materials. *Advanced Materials*, vol. 11, no. 16, 1999, pp. 1354-1358.

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